

FINAL REPORT

PROJECT TITLE: ARCTIC/NORTH PACIFIC OCEAN ENVIRONMENTAL STUDIES

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CONTRACT NUMBER: N00014-93-C-0217

PERIOD OF PERFORMANCE: 6/30/93 – 6/30/97

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The project began in 1993 as a effort to design and construct an Arctic capable low frequency acoustic source at 20 Hertz with acoustic power of 195-200 dB. The objective of the effort was to test the feasibility of acoustic monitoring of the Arctic Ocean and ice cap using long range low frequency acoustic propagation, by answering the fundamental questions: (1) What source level would be required to reliably propagate at 20 Hertz across the Arctic Basin?, (2) Will the Arctic acoustic channel be stable enough to permit precise phase and/or travel time measurements?, and (3) Will modes/rays be stable, identifiable and predictable?

The design study of Arctic capable acoustic sources was completed in December 1993 and a decision was made to go forward with the manufacture of an acoustic source by the Institute of Applied Physics, Nizhny Novgorod, Russia. The results of the design study by the Institute of Applied Physics are included in this report. It was also decided to support a experiment in the Arctic in April 1994 to be known as the Transarctic Acoustic Propagation (TAP) Experiment. The objectives of the experiment would be to test the acoustic source and the hypotheses of acoustic monitoring of the Arctic Ocean.

As part of the ONR/NSF sponsored SCICEX-95 submarine research cruise to the Arctic, SAIC proposed research to study measuring the ice properties and volumetric sound speed characteristics along several tracks spanning the Arctic Basin. One of the tracks would correspond closely to a propagation path used during the Transarctic Acoustic Propagation (TAP) Experiment conducted in April 1994. Ice data and sound

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speed data collected along the tracks would be analyzed to provide statistical descriptions useful for making signal-to-noise ratio estimates for global warming signatures. Funding was added to this contract to provide for SAIC participation in the SCICEX-95 effort.

The Transarctic Acoustic Propagation (TAP) Experiment was conducted in April 1994. The experiment was staged from Longyearbyen on the island of Spitzbergen in Norway's Svalbard Archipelago, across the Fram Strait from Greenland. The Russian acoustic source was deployed at ice camp Turpan, which was located on the sea ice 320 miles north of Longyearbyen. The experiment consisted of sending acoustic signals for six days across the north pole from ice camp Turpan to a US ice camp Simi in the Beaufort Sea, north of Alaska, a distance of more than 1,600 miles. The signals were also received at a joint US and Canadian ice camp Narwahl in the Lincoln Sea, a distance of nearly 600 miles.

The TAP Experiment marked the first successful phase-coherent acoustic transmission spanning the Arctic Ocean. The major findings included: (1) that a source level of 195 dB at 20 Hertz would be sufficient for even the longest trans-Arctic acoustic paths, (2) the verification of the stability of the Arctic acoustic channel, even at trans basin ranges, for making precise phase change, and travel time measurements for the purpose of measuring ocean temperature changes, (3) the acoustic modes were stable, identifiable, and predictable, (4) the indication that Arctic Intermediate Water is warmer than what is in the GDEM climatology for the Arctic Ocean detected by an observed travel time of Mode 2 that is 1-2 seconds faster than predicted using the GDEM climatology (an unanticipated result with far-reaching consequences), and (5) the Russian electromagnetic source operated satisfactorily at a frequency of 19.6 Hertz and a power level of 195 dB. The report of the manufacture of the Arctic capable low frequency acoustic source by the Institute of Applied Physics is included in this report. The results of the TAP Experiment were reported in a EOS, Transactions, American Geophysical Union, article in July 1995. A copy of the article is included in this report.

During the TAP Experiment, a marine biologist from the Woods Hole Oceanographic Institute was present at the Turpan ice camp to monitor the possible effects on marine life from the acoustic source that was in operation at the camp. Following the completion of the experiment, a modest study was initiated by Russian scientists to determine the extent of marine life activity in the East Arctic where the acoustic source was deployed. The results of the study are included in this report.

For the SCICEX-95 effort, we participated in the SCICEX planning meetings in December 1994, and provided inputs and comments on the scientific test plan. Provisions were made in the test plan to have one of the submarine tracks correspond closely to a propagation path used during the TAP Experiment. We participated in the data review following SCICEX-95, and subsequently have obtained the sound speed data obtained during the AO94 cruise to the Arctic. We have compared the SCICEX-95 and AO94 sound speed data taken at 15 sites across the Arctic that were separated by distances varying between 10 nautical miles to 160 nautical miles. The SCICEX-95 sound speed data matches very well with the AO94 data, the closer the measurement

location the better the agreement. The data also supports the conclusions drawn by the TAP analysis that the Atlantic Intermediate Water (AIW) is crossing over the Lomonosov Ridge.

Collaboration of analysis results with fellow scientists and SCICEX participants resulted in generating several joint publications. Presentations of oceanographic and acoustic results were given at several international conferences. SAIC presented two papers related to SCICEX data at the AGU Oceans Meeting in February 1996. Acoustic model results based on SCICEX data were presented at the Proceedings of the 3rd European Conference on Underwater Acoustics, in Greece, in June 1996. In addition, an invited paper was presented at the Fall AGU Meeting in December 1996. Abstracts of these presentations are included in this report.

Collaboration with Russian colleagues has allowed generating a large historical Arctic database containing tens of thousands of temperature, salinity, and sound speed profiles (including MOODS data, NOAA's World Ocean Atlas data, and hundreds of historical Russian profiles). As unfunded participants in the SCICEX-96 cruise, SAIC provided the Arctic Submarine Laboratory (ASL) with SSXCTD probes to be included in an Arctic Basin transect. In preparation for SCICEX-96, SAIC shared environmental analysis software, and fall rate correction techniques and software with North Carolina State University (NCSU) and ASL. A summary of expected measurements in the SCICEX-96 test area based on our historical Arctic database was also distributed prior to the cruise.

Results

Physical and acoustic data collected from the Arctic since 1990 are causing us to revise our understanding of upper Arctic Ocean features, boundaries, water masses, and circulation. Analyses of profiles collected during SCICEX-95 have allowed significantly better understanding of the hydrography of the Arctic region. The results of the TAP Experiment and comparison of SCICEX-95 Transarctic data to historical data showed that warmer Atlantic Intermediate Water (AIW) in the Eastern Arctic occupied a larger area than was historically known. Our analysis has shown an intensification and shifting in the front between Atlantic and Pacific Waters from near the Lomonosov Ridge toward the Makarov Basin. Warm water cores were observed in the upper AIW water near the leading edge of this frontal region and over the Northwind Ridge to the west. The warm cores extended 200 meters vertically, 100-300 kilometers horizontally, and coincided with the location of topographic ridges. These warm cores are characterized by 1 deg C warmer temperature than found in historical data. Many thermohaline inversions were also observed in the AIW. These inversions extended 100 kilometers horizontally, 50 to over 200 meters vertically, and were aligned with constant density surfaces.

Downwelling of colder Arctic Surface Water (ASW) was observed over the Mendeleyev and Canadian Basins. The upper 100 meters of ASW east of the Northwind Ridge displayed a 3 psu increase in salinity compared to historical data, while a 3 psu

decrease was observed to the west of this ridge. Similarly, temperatures in the ASW were over 1 deg C colder east of the Lomonosov Ridge, and approximately 1 deg C warmer west of the Northwind Ridge. Results from acoustic model runs demonstrate the feasibility and potential use of acoustic thermometry in monitoring long-term temperature change. Modeled travel times, based upon SCICEX measurements, agree more closely with measured arrival times from the TAP Experiment than does historical data; emphasizing the importance of recent measurements in determining temperature change.

Relationship to Other Projects

Work under this contract has directly supported the goals of the December 1994 Gore-Chernomyrdin Commission Memorandum of Understanding (MOU) on Coordination in Science and Technology. The Arctic Climate Observations using Underwater Sound (ACOUS) Project is a joint US-Russian basic research program currently underway to synoptically detect changes in the temperature of the Arctic Ocean and in the Arctic polar ice cap. The synergy between this contract effort and the ACOUS Project has provided important data necessary to baseline Arctic circulation changes and refine the acoustic 'thermometer' being developed for the Arctic.